

Kartchner Caverns State Park Environmental Monitoring Station Development Project

By Henry Schneiker
June 4, 2002
Proprietary - Copyright 1999 - 2002

The purpose of this project is to develop a cave-proof Environmental Monitoring Station, demonstrate the data collection process, make possible the deployment of a network of monitoring stations throughout Kartchner Caverns and thus provide for the long term study of the Kartchner Caverns environment with publication of results.

Problem Statement

Arizona State Parks is developing Kartchner Caverns for commercial tours by installing tunnels, airlocks, walkways and electric lights. The Throne and Rotunda portion of the cave has already been commercialized and opened to the public. The Big Room section of the cave is now being developed and the Park would like to open this section within the next two years.

As part of Kartchner Caverns State Park's commitment to conservation, it is necessary to monitor various environmental parameters to ensure no harm comes to the cave environment. Failure to provide proper conservation management could result in damage to the cave, loss of a large bat maternity roost, bad publicity for Arizona State Parks and significant economic loss for Kartchner Caverns State Park as well as the surrounding community.

Kartchner Caverns is a wet cave with numerous live formations. The live formations depend upon a thin coating of water to maintain their luster and brilliance - in essence, their beauty. The live formations also depend upon the water for their continued growth. It is the mystique of a fabulous live cave in the desert and the lustrous quality of the formations that makes Kartchner Caverns such a showpiece and attracts so many tourists.

Areas of the Throne and Rotunda rooms are now visibly dryer, with a subsequent loss of luster on live formations. Further, data shows a temperature rise as well as a drop in relative humidity. There has also been negative publicity as a result of this drying - a level of drying never witnessed prior to the commercialization process. One of the unanswered questions is where all the water going - a question that can only be answered through detailed study.

The baseline research was originally performed through contract and then continued through Kartchner Caverns State Park personnel. Presently, the humidity data is based on reporting the amount of water lost from evaporation trays, manual wet bulb/dry bulb sling psychrometer and low resolution electronic sensors.

The current instrumentation used to track humidity is rather crude. A sling psychrometer cannot resolve temperatures to sufficient accuracy for detailed humidity measurements and requires a skilled human operator. Commercially available electronic humidity sensors become unreliable as the humidity exceeds 95%. Current instrumentation cannot measure humidity to the required level of accuracy. The difference between a cave drying out and maintaining its moisture can be the difference between 99.0 and 99.5% relative humidity. Evaporation trays are still being used to collect data but require a highly skilled human operator with a maximum sampling rate of one measurement per month. It is difficult to get accurate and repeatable measurements using evaporation trays. In any case, there is no currently available system that will allow remote data collection.

Kartchner Caverns is the home of a large maternity colony of *Myotis velifer* bats numbering around 1000 individuals. These bats happen to reside in the Big Room in the front section of the cave during the summer months. Before the Park can open the BigRoom section to tours, it must be determined whether the bat roost environment will be affected by the added heat from electric lights and transformers or by modified air flows caused by the use of the new tunnels by tours. Failure to properly determine the adverse affects of these cave modifications on the bat roost microclimate could allow the environment to be adversely affected and thereby cause the maternity roost to be abandoned. In any case, no tours will be allowed during the summer months when the bats are in residence.

The key to both of these management problems is having accurate data from an in-cave environmental monitoring system. For management purposes, humidity and other environmental factors must be measured to very high accuracy at regular intervals during the day. These measurements provide data on the affects of events as they are taking place, including tours and barometric pressure changes. Further, it is necessary to take measurements throughout the cave in order to determine where problems are originating and to determine the full extent of the problem. Measurements should also be taken in areas of the cave where no changes are expected to provide a control.

The typical underground environment is fairly stable. As a result, monitoring instrumentation must be able to reliably detect subtle changes. Historically, it has been difficult to accurately measure humidity differences above 95% and temperature differences below 1°C. In order to determine if an environment is changing, we must be able to take detailed accurate data over extended time periods - which can span years or even decades. We must have confidence that the data we took at the beginning of the study is just as accurate as the data taken at the end of the study. In particular, it is important that instrument readings do not drift over time. Finally, the underground environment is hostile to electronic devices. As a result, monitoring instrumentation must be able to withstand extended periods in this hostile environment without affecting the accuracy or repeatability of readings.

Project Significance

Providing an accurate environmental monitoring system allows management to document any changes to the environment. Long-term data collection allows management to separate seasonal or other temporary changes from changes caused by commercialization of the cave. These changes will provide the first warnings of a problem. Early detection allows early intervention. Once the problem has been identified and corrected, the environmental monitoring system allows management to document that the problem has been corrected and the environment has returned to its previous state. The ability to monitor and document the cave environment also shows due diligence on the part of Kartchner Caverns State Park and Arizona State Parks. Allowing for independent data analysis provide verification and credibility.

Currently there are no cave-proof instrumentation packages that are capable of making precise measurements over extended periods. We must be able to accurately monitor temperature, humidity and other environmental factors to adequately manage the cave system. It is important that the data can resolve subtle changes that can take place over relatively short time periods of less than an hour. The data must be available over a time period spanning decades to allow yearly cycles to be differentiated from lower frequency weather patterns or the on-going affects of commercialization. The systems must be able to survive the hostile wet cave environment.

This project is the first of three projects to demonstrate that such a package can now be built. The three projects are: 1) build the initial unit and use it for an actual research, 2) install a network of 15 to 20 monitors to monitor the whole cave and to upgrade the visitor center display and 3) provide on-going independent data analysis, publication and system maintenance.

Kartchner Caverns State Park will be the test bed for the first high quality environmental monitoring system ever installed in a cave system. We think this will set the standard for how to

properly collect the detailed cave environmental information and how to use that data in the management of the cave system. This project will also show the public that Kartchner Caverns State Park is a leader in cave management and will result in many significant positive press opportunities.

The Development Process

We have completed the feasibility study that shows this project can be done with currently available components and at a low risk. The preliminary requirements, design, component selection and documentation for this project have already been completed. The draft design specification is available at:

<http://www.hdssystems.com/AirStudyStationSpec.pdf>

This project will take the next step, which is to prototype and build a cave-proof environmental monitoring station capable of monitoring multiple parameters to high resolution over extended periods. Initial parameters include air, water and soil temperatures to 0.001°C, relative humidity to 0.01% near saturation, barometric pressure to 0.01mb, wind direction and speed to 1mm/s and event counting up to 65,000 events per sample interval. The successful completion of this project is predicated on sufficient funding being available to complete all phases.

The monitoring station will be able to collect 50,000+ samples per battery pack for a total of 100,000+ samples per set of batteries and store 1.3+ million samples. Although the Kartchner Caverns installation will use a tethered configuration that supplies external power, the batteries will supply backup power so data collection can continue in the event outside power is lost. Measurements will be taken at regular intervals that can range from seconds to hours or days. More frequent measurements will consume more battery power. The design goal is to allow for measurements to be taken every 10 minutes for one year using one battery pack. Data is preserved in non-volatile memory in the event that all power sources fail.

Data is stored as ASCII text characters. This allows the data to be easily imported into spreadsheets or custom programs for analysis. Furthermore, the data is always kept in a human readable form. During installation, a file header is generated that describes the station location and sensor calibration parameters. For each sample interval a string of readings is generated. A typical set of readings along with a field identifier comment would look like:

```
/location      , date-time      ,drybulb,wetbulb,  baro,   wind,p,ck
KCSPKarta31   ,2001.01.31 14:38:22, 20357, 20352, 83671,   4,0,7E
```

This project is composed of two phases to develop a custom environmental monitoring station that can be produced in quantity. The first phase will prototype the electronic design and construction methods. The prototype station will be calibrated with sufficient accuracy to allow the full resolution of the sensors to be realized. The prototype will be further tested in Kartchner Caverns for several months. Based on the experience gained from these tests the prototype will be further refined and a production-representative monitoring station will be produced. The second phase will add additional sensor capabilities, further station refinements and incorporate a rigorous NIST traceable calibration. Custom circuit boards will be finalized and this will allow us to easily build a large number of identical units. The completion of each phase is contingent on the availability of sufficient funds.

Prototyping is an iterative process. The process starts by building the basic functional part as a proof-of-concept implementation. Once the basic functional concepts are demonstrated, other features are added and tested. Finally a clean implementation with all features is produced. For example, to prototype a sensor, the first iteration prototype consists of attaching parts to a perf-board with wires soldered between the parts. This prototype is then tested and any problems are resolved. The second iteration prototype consists of laying out a circuit board, fabricating the circuit board and populating the board with parts. The populated board is tested to verify proper operation. If problems are found that cannot be easily bypassed, another circuit board

will be laid out, fabricated, populated and tested. This process continues until an acceptable circuit board is achieved.

It is normal procedure to budget for one proof-of-concept and three board iterations (printed circuit board layout and fabrication) per circuit board. For this project we have four circuit boards: the main controller and three sensors boards. The main controller circuit board will include the microprocessor, data storage, interface logic and power supply circuitry. The sensors will present a common interface to the controller. Each sensor type will need a specialized circuit board - currently a temperature sensor, a pressure sensor and a wind sensor board.

The delicate analog signals and complex digital electronics require the use of double-sided circuit boards. Special conformal coatings will be used to waterproof the electronic circuitry. Corrosion resistant materials will be used in any exposed locations that cannot be otherwise protected.

The proof-of-concept implementation (first iteration prototype), intermediate circuit board iterations and associated components are considered throwaways. The early implementations are often exposed to stresses or damage during initial testing due to bugs in the circuitry or attempts to work out circuitry, assembly or packaging problems. In general, it is not practical to recover parts from early implementations for use in later implementations. The cost of recovery and risk of damage during the recover process normally result in all or most parts from early implementations becoming scrap.

The standard configuration requires 2 temperature sensors, one barometric pressure sensor and one wind sensor. Additional sensors can be added to increase the number of environmental parameters being monitored.

This project has several prioritized goals.

- The first goal will be to prototype the temperature and barometric pressure sensors and fan control. These are the heart and sole of the monitoring station. Due to the high resolution involved, care must be exercised to minimize electronic noise pickup and minimize measurement error due to the electronics package. Low-resolution calibration will be used during phase one to minimize cost. A single sensor will be used as a transfer standard so sensor-to-sensor span and calibration points will match.

Testing will ensure proper sensor control and measure noise, repeatability, drift and settling time to ensure the sensors can match the specifications. Any problems will be corrected.

- The second goal will be to prototype the wind direction and speed sensors. Low resolution calibration will be used during phase one to minimize cost.

Testing will ensure proper operation of the wind sensor.

- The third goal will be to prototype the microprocessor, data storage, interface logic and power supply circuitry. This forms the core of the monitoring station.

Testing will validate reverse polarity protection, primary battery pack selection, auto fail-over to secondary battery pack, in-circuit programmability and in-circuit debugging. Any problems will be corrected.

- The fourth goal will be to prototype the microprocessor control software. The microprocessor control software controls the sensors, data acquisition, data conversion, data formatting, data storage and data retrieval.

Testing will validate the use of calibration data to generate final sensor values, data formatting in a standard format, storage and retrieval of the resulting data. Any problems will be corrected.

- The fifth goal will be to prototype the NIST-traceable calibration system. This requires specialized temperature chambers that utilize calibration transfer standards.

Testing will ensure proper operation of the calibration systems.

An in-cave system test will allow us to verify proper operation of the whole system under real conditions. During this test we will compare our humidity readings and calculations against the data from evaporation trays that are currently used for data collection. Any problems will be corrected.

The final application test will be to monitor a critical cave area, such as the bat roost. The monitoring station will be placed and remain at the test location for several months. During the test, we will connect a remote serial port to the station so we can monitor the test and verify proper operation even when the bats are occupying the roost. Further, before the bats return, the Park can perform experiments with the lights and tunnel doors to see what affects they have on the bat roost microclimate.

Project Schedule

The tentative project schedule covers about 18 months as follows:

- July 1, 2002: Start (assumes funding availability by this date). Order parts and materials for prototype. The lead-time for some parts is 8 to 10 weeks. Finalize schematics.
- October 1, 2002: Begin building prototype. Construction can proceed even if not all parts have been received.
- November 1, 2002: Begin preliminary prototype testing. Prototype should be fully assembled and ready for initial power testing and debugging. Publish preliminary project report when this phase is completed.
- March 1, 2003: Begin in-cave system testing.
- April 1, 2003: Begin in-cave application testing. Prototype will be placed in bat roost (after the bats have left) to monitor the roost environment or other suitable location. Start the second phase - begin prototyping the calibration system.
- July 1, 2003: Recalibrate the in-cave unit using the calibration system. Resolve any issues uncovered during testing. Continue testing.
- January 1, 2004: Official end of project. Publish a final report.

Project Budget

All three projects are listed.

Project I Budget - Build Initial Monitor

The first project will build and test the initial prototype Environmental Monitoring Station. Kartchner Caverns State Park (KCSP) is funding the hardware development with a few additional expenses noted. Software and other labor expenses are currently TBD, with anticipation that Friends of Kartchner Caverns will cover these expenses.

Travel

Kartchner Caverns (20 trips @ 110 miles at \$0.345/mile)	759	KCSP
Miscellaneous travel (400 miles at \$0.345/mile)	138	KCSP
Subtotal:	\$897	

Facilities, Equipment and labor

Electronics lab	Facility	HDS
Development support	Facility	HDS
Oscilloscopes	Equipment	HDS
Power supplies (current and voltage controlled)	Equipment	HDS
Digital volt/amp/ohm meters	Equipment	HDS
Solder stations	Equipment	HDS
Computers and general office software	Equipment	HDS
Microprocessor programming system	Equipment	HDS
Compiler, debugger and translation software	Equipment	HDS
Labor (32 weeks @ \$75/hour including overhead)	\$96,000	TBD

Components and fabrication services

Station hardware for prototyping	\$5,500	KCSP
Development systems	\$4,000	KCSP
Production development	\$7,000	KCSP
Calibration standards	\$9,500	KCSP
Calibration chamber development	\$4,000	KCSP
Miscellaneous expenses	\$4,000	KCSP
Subtotal:	\$34,000	

Miscellaneous

Film and processing	\$90	KCSP
Postage	100	KCSP
Subtotal:	\$190	

Total:	\$35,087	KCSP
	\$96,000	TBD

Notes: KCSP is Kartchner Caverns State Park, FKC is Friends of Kartchner Caverns, HDS is Henry Schneiker in conjunction with HDS Systems. TBD - to be decided.

The deliverables to Kartchner Caverns State Park are: one Environmental Monitoring Station in standard configuration, one preliminary project report and one final project report. Other hardware, software and intellectual property used in the design, development, prototyping, production, calibration, testing, delivery and reporting of the Environmental Monitoring Station shall be retained as the sole property of HDS Systems, Inc. The successful completion of this project is contingent on a timely full budget funding.

Project II Budget - Network Installation

The second project will install a network of 20 stations. The cost of the network includes installation and testing. The wire between the Station and the data collection processor has already been installed and is thus not included. Although Kartchner Caverns State Park is listed to provide primary funding of this project, it is possible part of the project will be paid for through Friends of Kartchner Caverns.

Travel

Kartchner Caverns (20 trips @ 110 miles at \$0.345/mile)	759	KCSP
Subtotal:	\$759	

Network

Monitoring Network (20 stations @ \$4000 each, includes installation)	\$80,000	KCSP
Upgrade display in Visitors Center	\$15,000	KCSP
Subtotal:	\$95,000	

Miscellaneous

Film and processing	\$90	KCSP
Postage	100	KCSP
Subtotal:	\$190	

Total: \$98,949 KCSP

Notes: KCSP is Kartchner Caverns State Park, FKC is Friends of Kartchner Caverns, HDS is Henry Schneiker in conjunction with HDS Systems. TBD - to be decided.

The deliverables to Kartchner Caverns State Park are: all sensors installed, tested and connected to the wiring supplied by Kartchner Caverns State Park and one upgraded and installed display. The upgraded display will display selected temperature and humidity information from the Monitoring Network. The information will be supplied in real-time to the display by Kartchner Caverns State Park.

Project III Budget - Ongoing Research and Publication

This project is an on-going project and the amounts listed are for the first year only. Future years can be increased from time to time to cover additional requirements. Although the funding source listed is TBD, it is anticipated that Kartchner Caverns State Park or Friends of Kartchner Caverns will cover the expenses.

Travel

Kartchner Caverns (12 trips @ 110 miles at \$0.345/mile)	455	TBD
Subtotal:	\$455	

Research and Publication

Yearly analysis and publication of data	\$7,000	TBD
Yearly network maintenance (inspections, verifications)	\$3,000	TBD
Miscellaneous	\$2,000	TBD
Subtotal:	\$12,000	

Total: \$12,759 TBD

Notes: KCSP is Kartchner Caverns State Park, FKC is Friends of Kartchner Caverns, HDS is Henry Schneiker in conjunction with HDS Systems. TBD - to be decided.

The deliverables to Kartchner Caverns State Park are: periodic visits to inspect and verify proper operation of the network, data analysis, graphing and independent annual reporting of the Monitoring Network data.

Participants

HDS Systems, Inc. is a consulting firm specializing in custom projects and light manufacturing. The company was first started in 1986 as a sole proprietor business and incorporated in 1997 to reflect its changing character. HDS Systems is owned and operated by Henry Schneiker (see below). HDS Systems has been involved with a wide variety of projects including the Kartchner Caverns Environmental Monitoring Station, Action Light, custom printing system, custom artwork production system and numerous software projects. These projects include hardware design, embedded controller programming and debugging, sensing systems, numerous operating systems, development systems and programming languages.

Henry Schneiker has over 25 years experience as computer and electronic engineer with strong background in business, project management and accounting. Henry has designed, prototyped, tested, documented and manufactured many products including complex software and hardware systems. Henry owns and has operated a private engineering firm for the last 18 years. Henry has over 30 years of caving experience and has been involved as a research assistant for various projects including Life in Extreme Environments (NASA) and Kartchner Caverns environmental baseline study and bat research. Henry is the designer for the Kartchner Caverns Environmental Monitoring Station.

Glenn Hamblin. Electronic engineer with strong experience in instrumentation, embedded controllers and networking. Glen has over 15 years experience in designing, prototyping, testing, documenting and overseeing the manufacture of hardware devices including industrial instrumentation, embedded hardware and software and device drivers.

Bob Buecher is a registered professional engineer and land surveyor in Tucson, Arizona. He was Project Manager for the Pre-development Baseline Study for Kartchner Caverns, in southern Arizona. There he directed studies of the cave microclimate, geology, mineralogy, biology, hydrology, geophysics, and mapping of the cave. The cave has a maternity colony of cave myotis (*Myotis velifer*) and the study stressed low disturbance techniques to monitor the bat population. He has been technical assistant on a 12-year study of the endangered nectar bat (*Leptonycteris corosoe*) in two roosts at Fort Huachuca, Arizona. He was also technical assistant on a Bureau of Land Management project to monitor 4 cave myotis roosts in the Guadalupe Mountains, New Mexico. He has designed and built cave gates, motion sensors, and bat counters to be used in remote sites.

Debbie Buecher holds a B.S. degree in biology and is currently pursuing a Master's degree in Wildlife Ecology in the Renewable Natural Resources Department at the University of Arizona. She has worked on bat research for 15 years throughout the United States. She worked for 16

years as a civil designer and was cartographer and hydrologist on the Pre-development Baseline Study for Kartchner Caverns, Arizona. Her current research involves analysis of species diversity, activity patterns and diet analysis between bats in a natural Sonoran Desert riparian corridor and an urbanized setting. Little is known regarding the impact of urbanization on desert bat communities and the results of her work should provide information for resource managers developing long-term management plans in the southwest.